

Diagnostic Imaging in Musculoskeletal Medicine



Shawn F. Kane, M.D.

Primary Care Sports Medicine Fellow

USUHS/DACH

Objectives

✦ Review the various imaging modalities available to the sports clinician with an emphasis on:

- indications;
- limitations; and
- contraindications.

✦ Discuss fundamental imaging strategies for the evaluation of site-specific sports-related injuries.



Radiography

- ◆ Process by which x-ray beams are projected through a subject and onto an image detector.
- ◆ “Whiteness” is a function of tissue radiodensity; higher mass, higher attenuation, more “white”
- ◆ The image is a projectional map of the amount of radiation absorbed by the subject.
 - Analog detector systems
 - Digital detector systems



✦ Analog systems: analog detector system e.g. film cassette.



✦ Digital systems: increasingly used in clinical settings.



Radiography

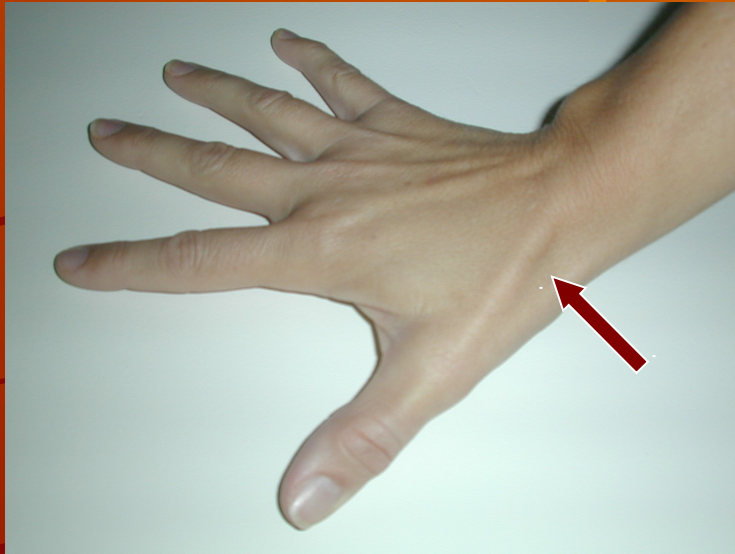
- ◆ Readily available, inexpensive, serving as the initial imaging study after a sports-related injury.
- ◆ Minimum of two-perpendicular views required.
- ◆ Complex injuries may require additional views



Two Orthogonal Views at a Minimum



Anatomic Snuff Box Tenderness



Complex Joints may
require additional views

Scaphoid Fracture

Radiography

◆ Principal Indications in Sports Medicine

- Initial diagnostic image for musculoskeletal injuries
- Excellent for fractures, arthritis, bone tumors, skeletal dysplasia
- Stress maneuvers
- Follow-up of disease



Radiography

- ◆ Advantages
- ◆ Limitations
- ◆ Contraindications



- Not to be used for injuries principally involving soft-tissues
- Pregnancy

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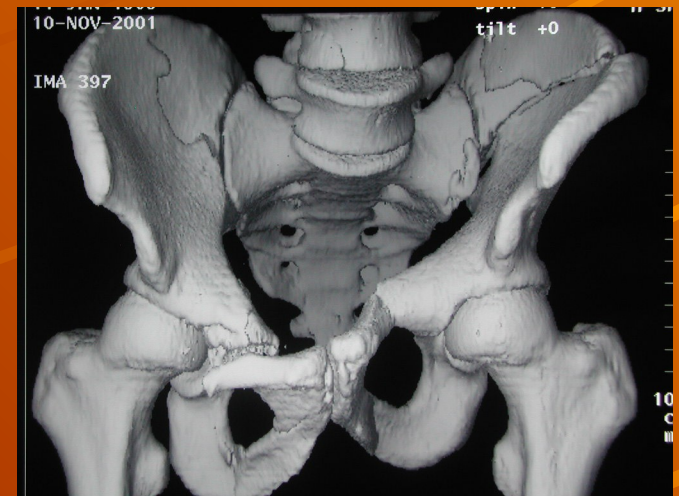
Computed Tomography

- ◆ CT uses x-rays to produce tomographic images.
- ◆ The computer reconstructs images to produce an computed map.
- ◆ Densities are measured in Hounsfield units (HU), where water is 0, and air is -1000.
- ◆ Images are typically grayscale, with denser objects appearing lighter.



Computed Tomography

- ✦ The grayscale images can be modified or “windowed” to show only densities that appear in a certain range e.g. bone or lung.
- ✦ Images can be reconstructed as 2D or 3D.
- ✦ Helical/Spiral Ct capability – volumetric data acquisition.
- ✦ Kinematic CT allows for the imaging of joint motion.



Computed Tomography

◆ Principal Indications in Sports Medicine

- Complex fractures e.g. spinal and hip
- Abdominal trauma
- Closed head trauma




Computed Tomography in Sports Medicine



Computed Tomography

- ◆ Advantages
- ◆ Limitations
- ◆ Contraindications

- 
- Can produce artifacts; motion and metal
 - Limitations for obese patients
 - Pregnant women should not have CT scans except in life-threatening emergencies

Magnetic Resonance Imaging

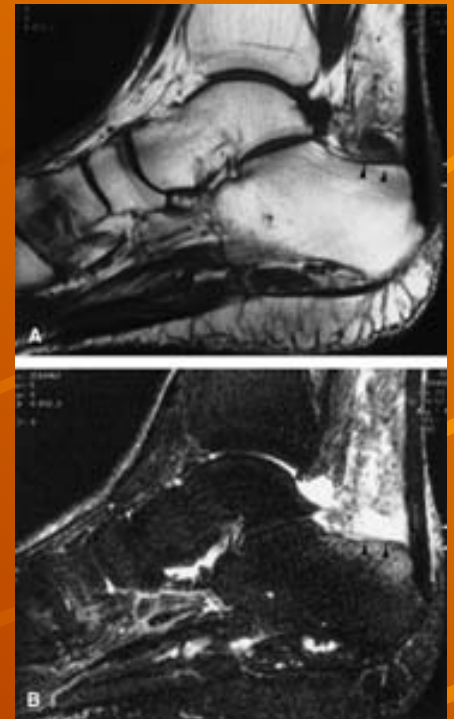
- ✦ Revolutionized the evaluation of sports injuries.
 - Based upon the number of free water protons within tissue.
 - Magnetic field aligns protons; then a radiofrequency pulse (excites) deflects the alignment.
 - Termination of pulse causes realignment (relaxation) and energy emission.



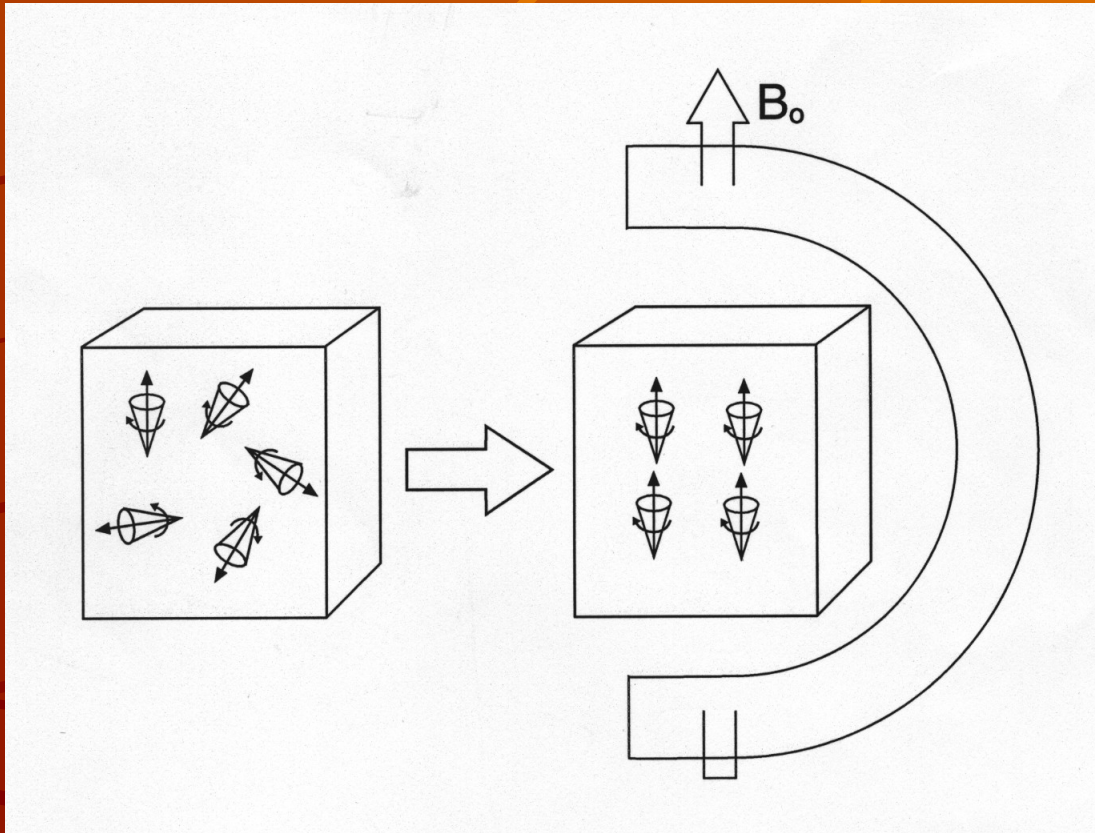
Magnetic Resonance Imaging

Terminology:

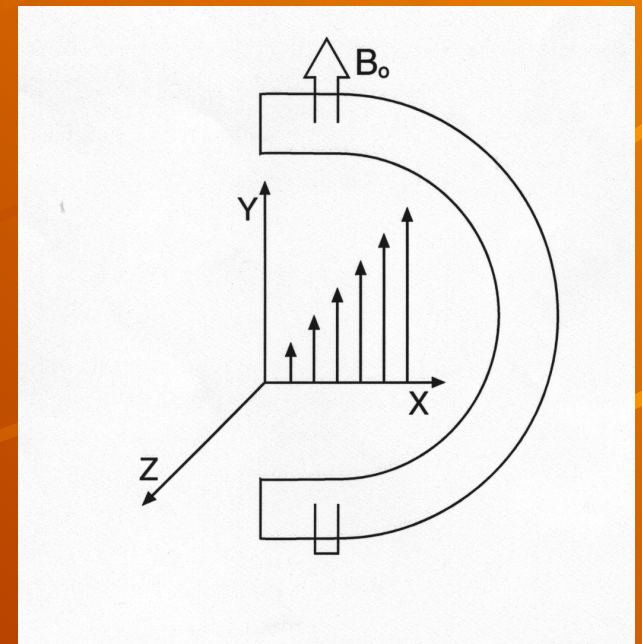
- **Pulse Sequence:** a specific series of RF pulses or gradient changes that results in excitation and realignment; spin-echo; gradient echo; inversion recovery.
- **Time to Recovery:** time to complete an RF pulse sequence.
- **Time to Echo:** time from pulse to coil listening for signal.
- **Inversion Time:** time between 180 and 90 degree pulses in an IR sequence.



MRI Physics “The Basics”



- Water protons align in external magnetic field
- Rate of precession directly related to strength of magnetic field

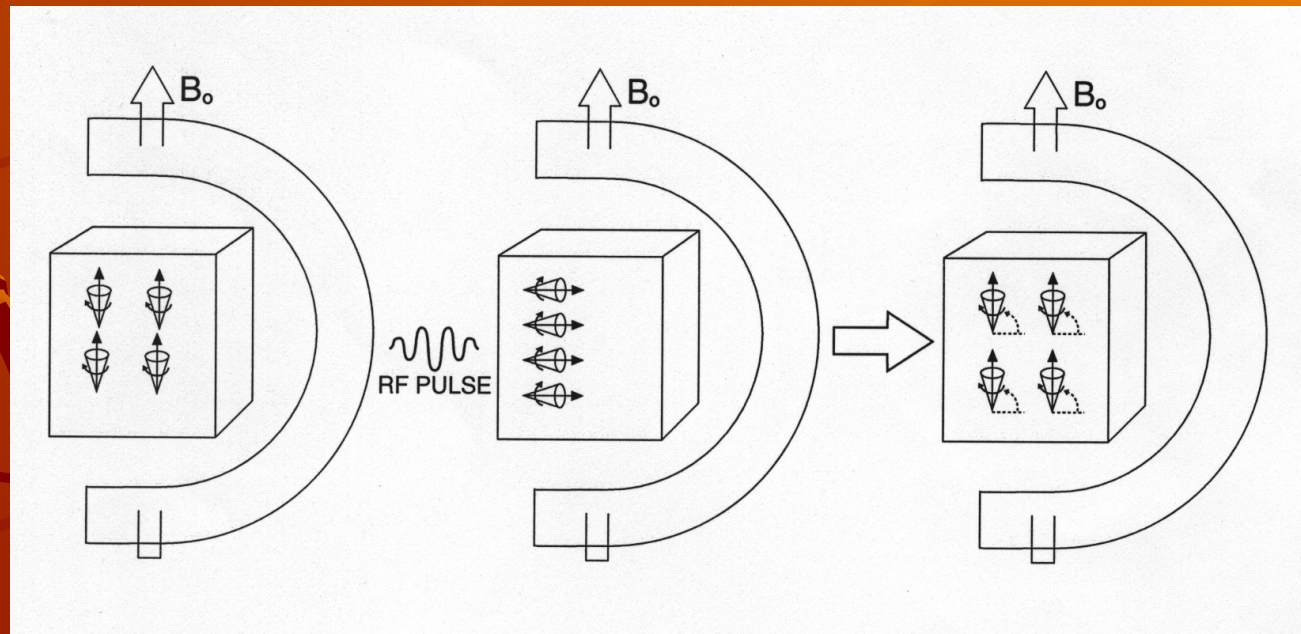


Gradient coils
3-D localization



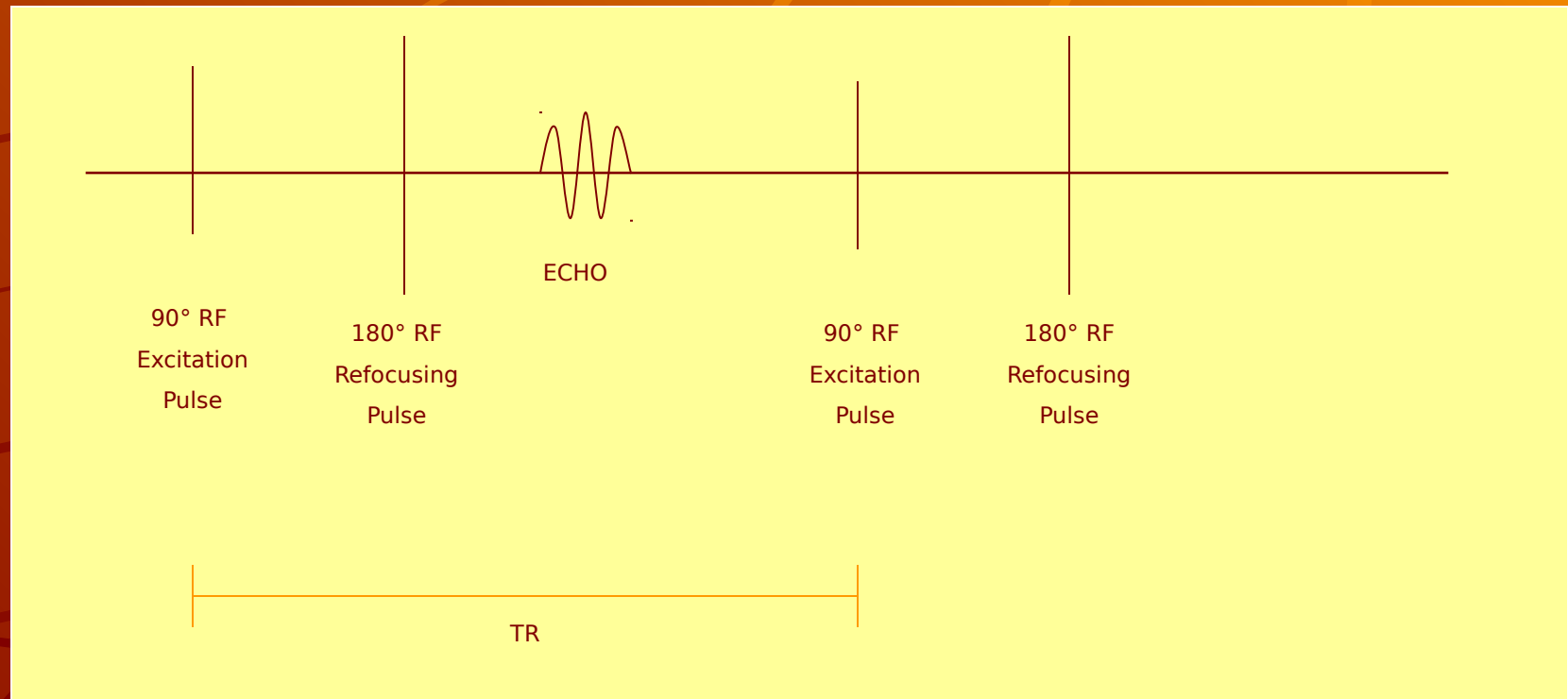
MRI Physics “The Basics”

Surface coil



- RF excitation pulse realigns the water protons
- Protons give off signal as they realign with the external magnetic field

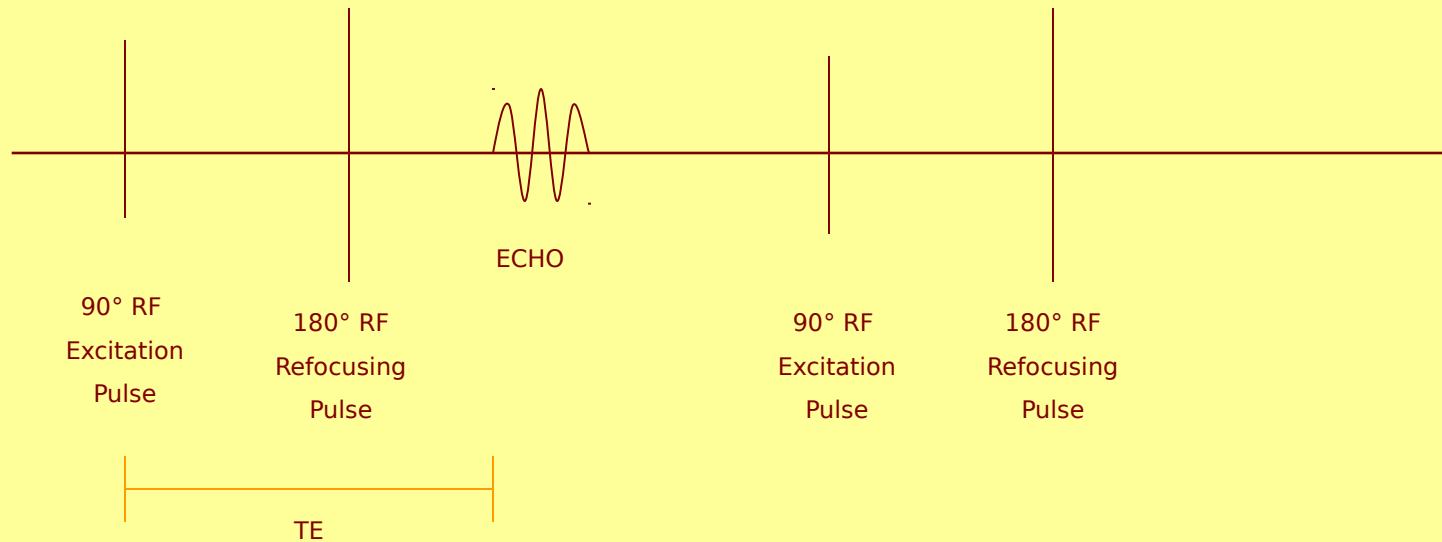
The Basic “Spin Echo” Pulse Sequence



TR “Time to Recovery”

- The time it takes to complete one entire cycle of the RF pulses
- Affects the T1-weighting of an image
- Directly related to the image acquisition time

The Basic “Spin Echo” Pulse Sequence

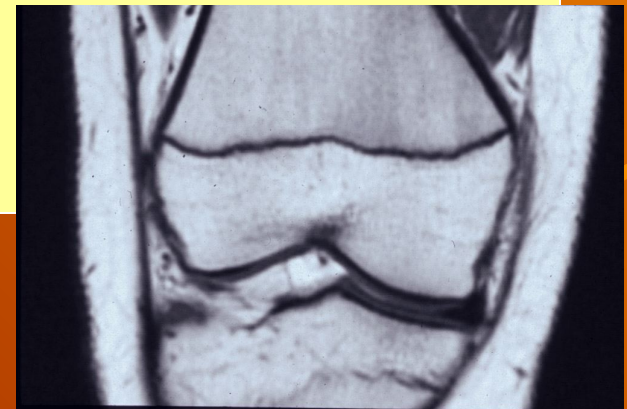
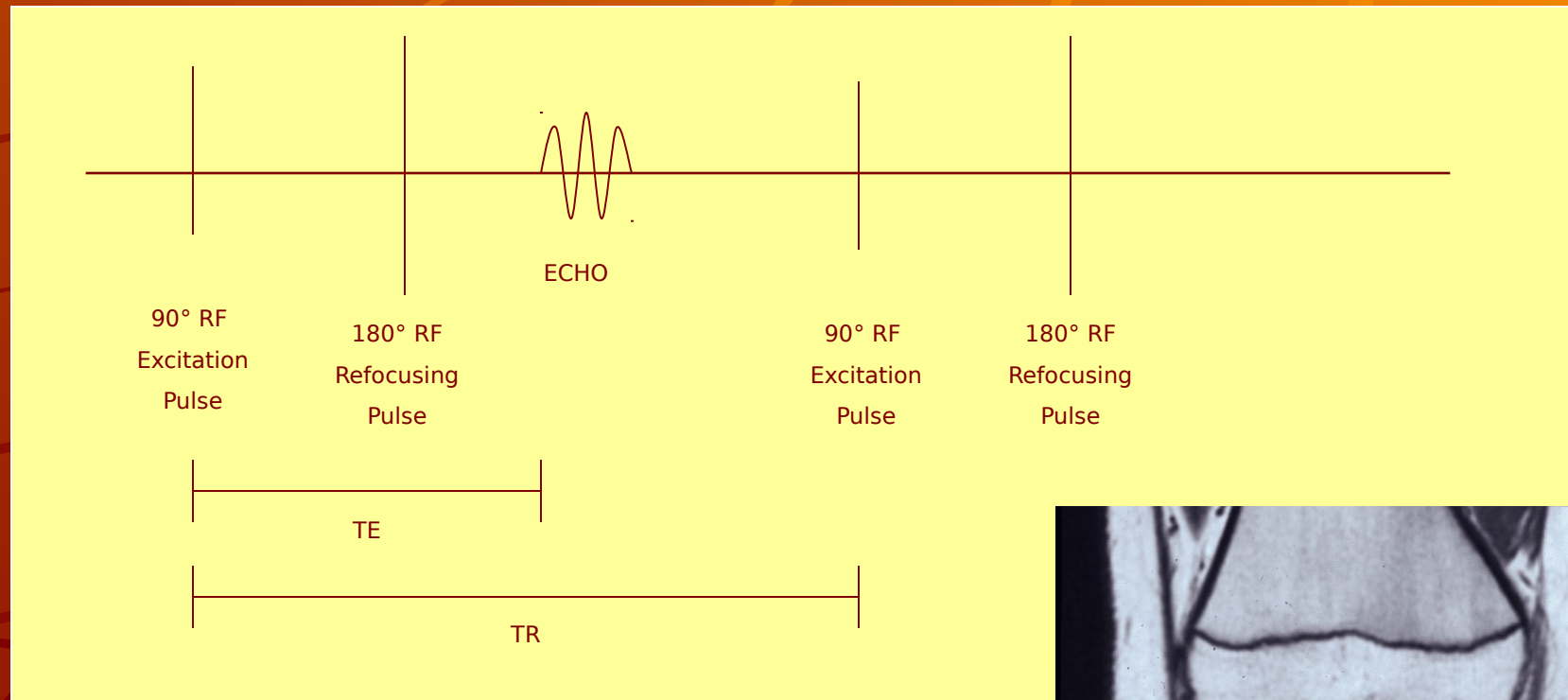


TE “Time to Echo”

-The time interval between the 90° RF pulse and when the receiver coil listens for the echo

-The length of the TE affects the T2-weighting of the image

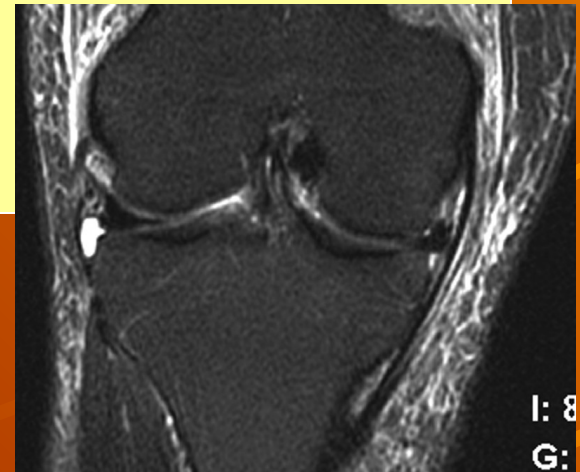
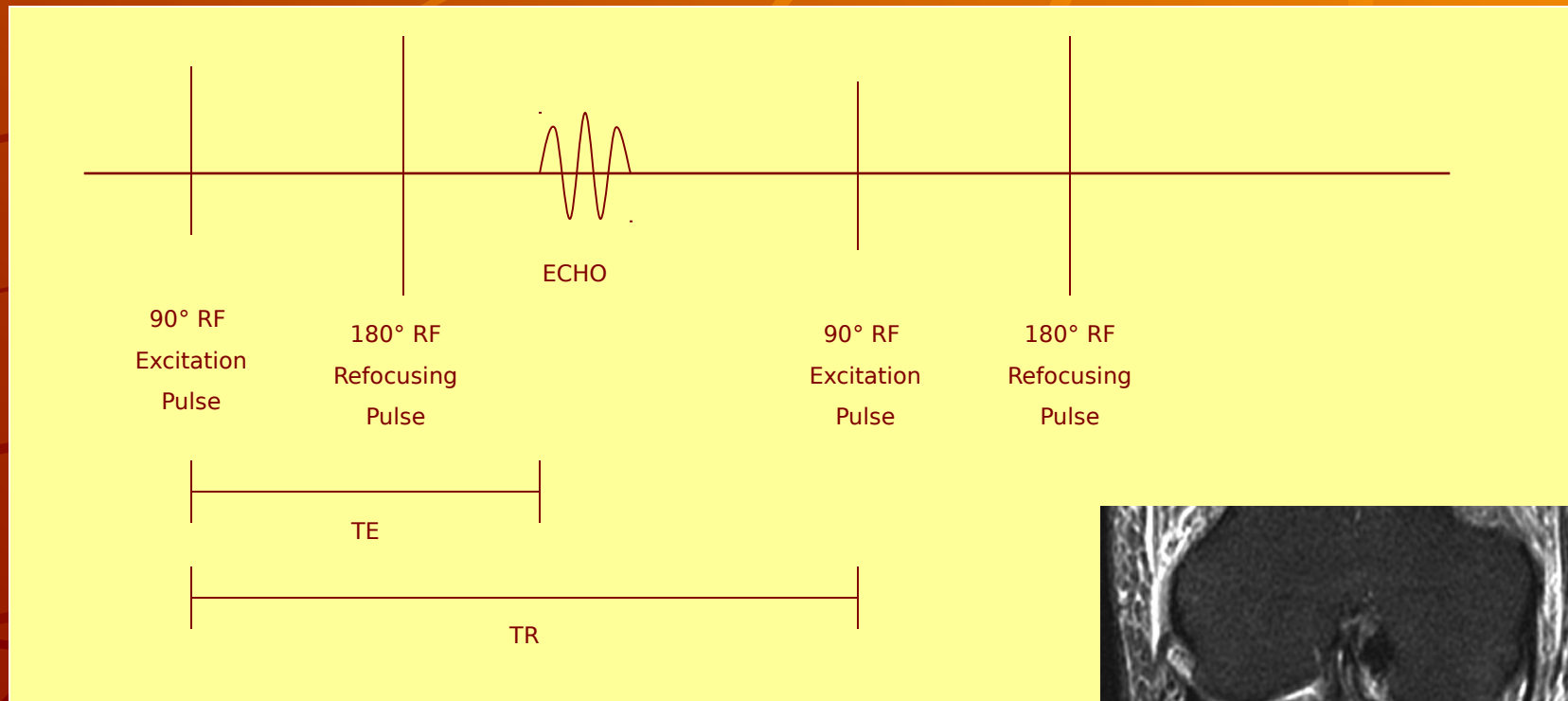
The Basic “Spin Echo” Pulse Sequence



T1-weighted image

- Short TR/TE (400-800 msec/ <30msec)
- Anatomic sequence
- Muscle/ water intermediate; fat bright; calcium/ fibrous tissue dark

The Basic “Spin Echo” Pulse Sequence



T2-weighted image

- Long TR/TE (>2000 msec/ <70msec)
- Pathology sequence
- Water bright; muscle intermediate; fat bright; calcium/ fibrous tissue dark

Magnetic Resonance Imaging

◆ Principal Indications in Sports Medicine

- Unmatched ability to evaluate soft-tissue injuries.
- Sensitive for bone marrow pathology.
- Contrast agents may be utilized e.g. gadolinium.



Magnetic Resonance Imaging

- ◆ Advantages
- ◆ Limitations
- ◆ Contraindications



- Magnetic effects; pacemakers, valves, pumps may malfunction.
- Metal foreign bodies can migrate.
- Tattoos and cosmetics can absorb heat.
- Cost.



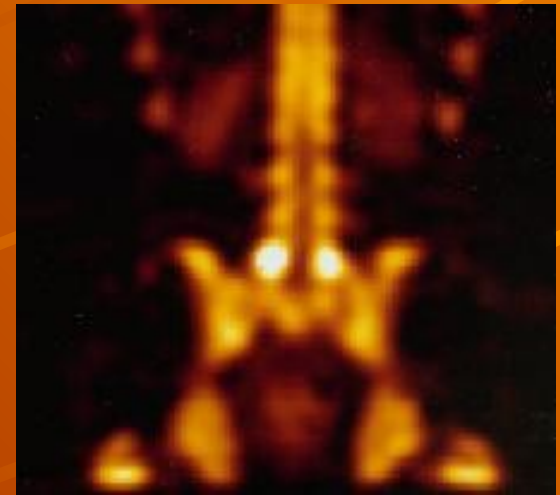
Scintigraphy

- ❖ Biologically active drugs (disphosphonates) are labeled with radioisotopes (technetium)
- ❖ The images produced by scintigraphy are a collection of radiation emissions obtained with a special camera (gamma camera)
- ❖ Two principal techniques in sports medicine:
 - Planar
 - SPECT



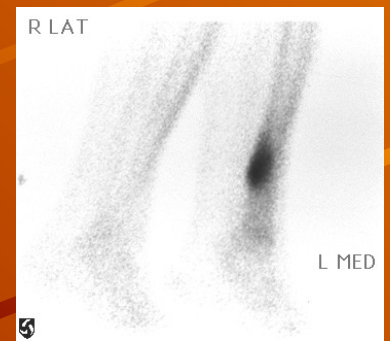
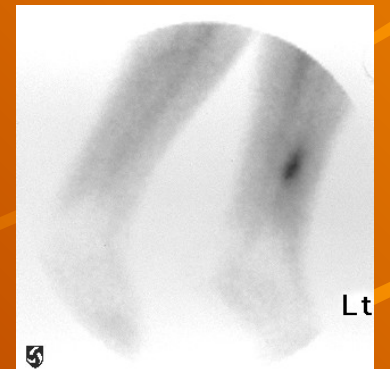
◆ Planar: single-projection images.

◆ SPECT: cross-sectional images.



Scintigraphy

- ✦ Triple phase bone scan:
 - The flow (perfusion) study - 60 seconds after injection
 - Blood Pool - tissue vascularity and tissue perfusion.
 - Delayed - 2 -3 hrs after injection; allows uptake into bone; clearance from extraosseous tissues.



Scintigraphy Stress Fractures

◆ Grading:

- Grade 1: small, mildly active confined to cortex
- Grade 2: larger with moderate activity
- Grade 3: cortical shaft into medullary region
- Grade 4: full bone width

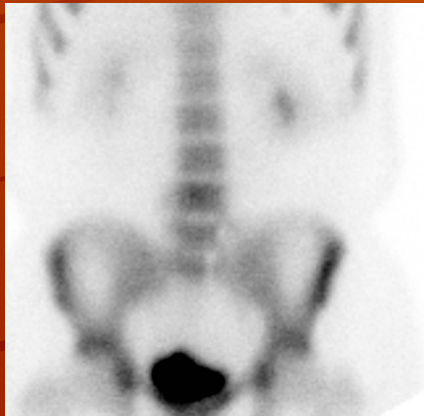
◆ Dating:

- All phase uptake: 0 to 4 weeks
- Blood pool and delayed: 4 to 12 weeks
- Delayed only: > 12 weeks



SPECT Imaging

Single Photon Computed Tomography



Posterior planar image



Coronal



Sagittal

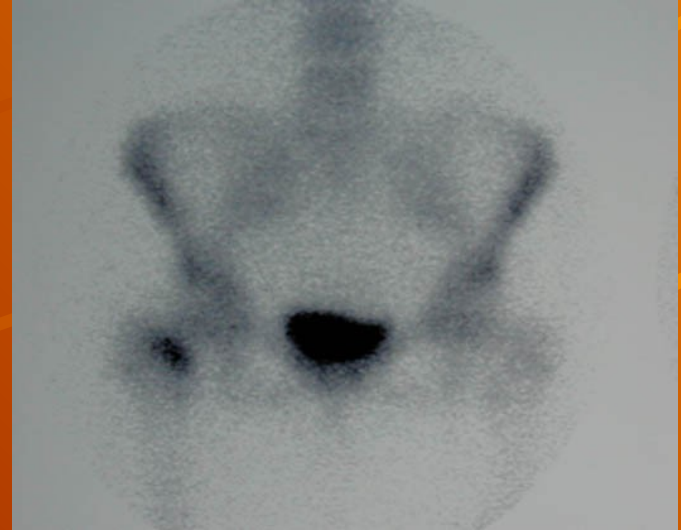


Axial

- enhanced tissue contrast
improved sensitivity and
specificity of
lesion detection/ localization

Scintigraphy

- ✦ Principal Indications in Sports Medicine
 - screening for skeletal metastases, stress and occult fractures, osteomyelitis, and evaluation of focal bone tumors



Scintigraphy

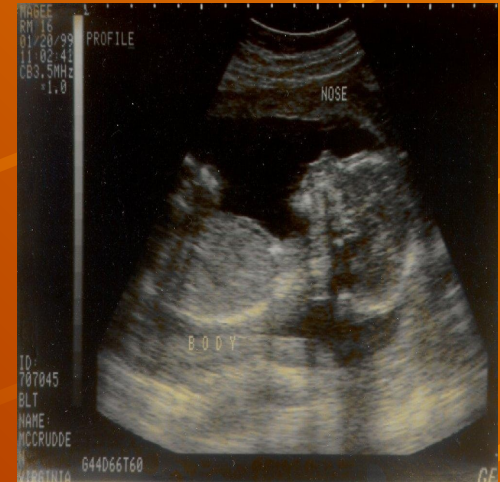
- ◆ Advantages
- ◆ Limitations
- ◆ Contraindications



- Scintigraphy exposes a patient to ionizing radiation
- Children and pregnant women should be carefully screened

Ultrasonography

- ✦ Ultrasound uses high-frequency sound waves to produce images.
- ✦ Waves are transmitted to the patient, and reflected back by different tissues, with a computer synthesizing a tomographic image.



Ultrasonography

- ◆ Echogenicity of a structure determines the brightness of an object; solid masses generally appear white.
- ◆ High frequency transducers provide better detail.
- ◆ Doppler ultrasound can be used to image motion.



Ultrasonography

◆ Principal Indications in Sports Medicine

- Very popular in Europe and Australia.
- Used to define extent of injuries in musculoskeletal structures such as tendons, and muscles.
- Can also be used to define masses and in localizing foreign bodies.



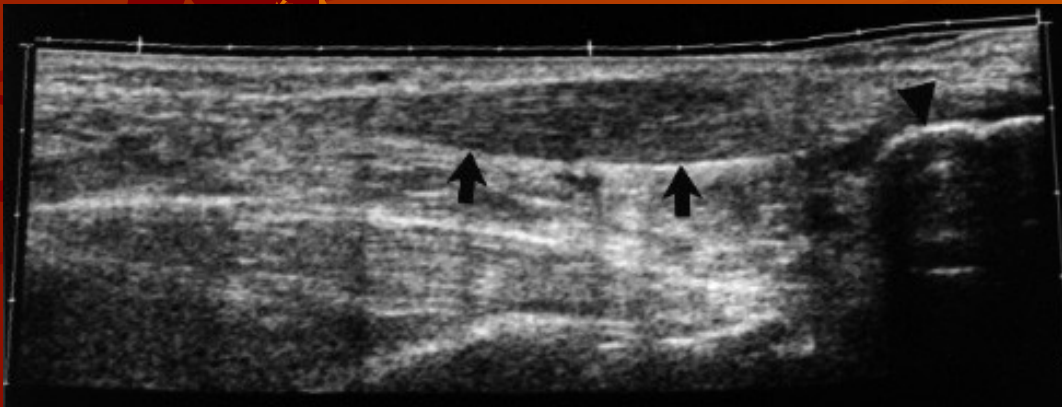
Tendons

-Tendon evaluation (Achilles, patellar, rotator cuff)



Normal Achilles
Tendon

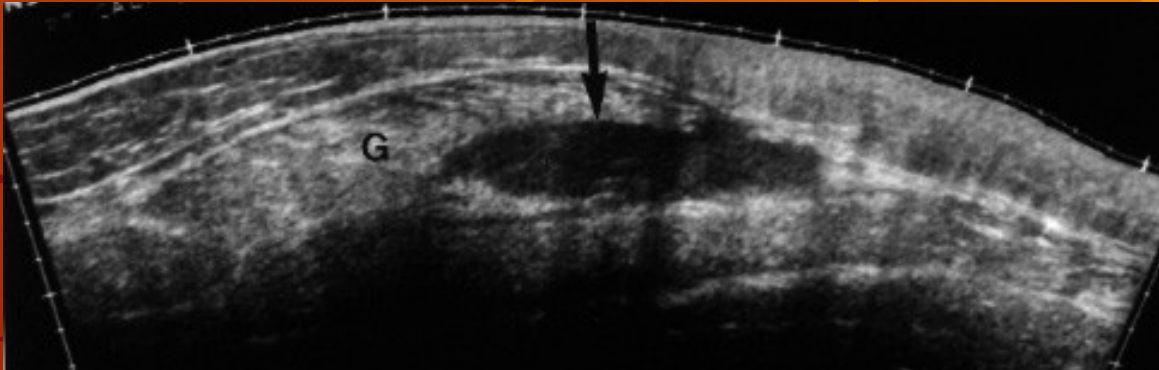
-Normal tendon: bright structure with longitudinally oriented bundles



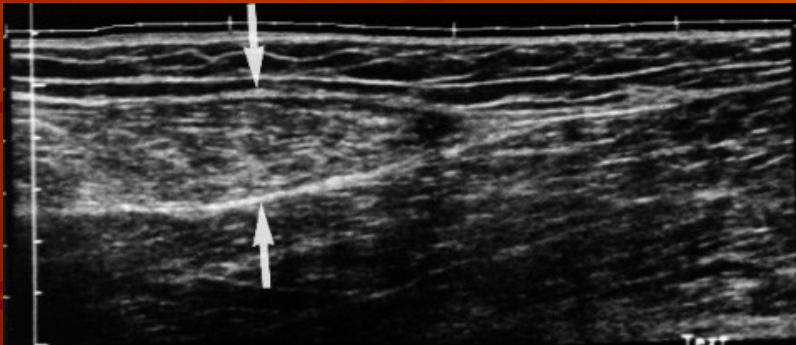
Chronic Tendonopathy

-Blurring, thickening, loss of normal architecture

Muscles



-Gastrocnemius with hematoma



-Torn Rectus Femoris muscle



-Dynamic evaluation of Rectus Femoris
-Complete disruption of fibers

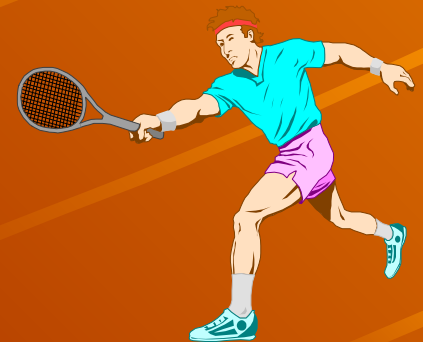
Ultrasonography

- ◆ Advantages
- ◆ Limitations
- ◆ Contraindications



- Cannot image inside bone, as bone cortex
- Heating of sensitive developmental tissues in fetuses
- Time consuming
- Highly operator dependent

Imaging of Site-Specific Sports-Related Injuries



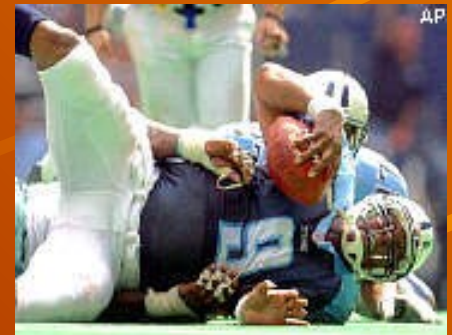
Head Injuries

- ◆ Acute Head Injury
- ◆ Post-Concussion Syndrome



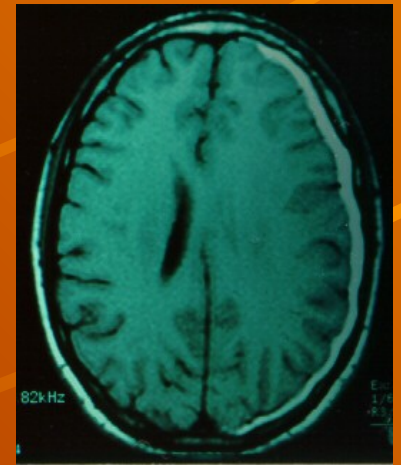
Acute Head Injury

- ✦ The general consensus in the literature is that CT scanning is the preferred imaging test of choice in the acute setting:
 - Ability to detect intracranial bleeding
 - Ability to detect fractures
- ✦ Controversy on who needs a CT:
 - Prolonged loss of consciousness, focal neurologic sign, depressed level or worsening level of consciousness.



Post-Concussion Syndrome

- ◆ Consensus in the literature is that patients with prolonged postconcussive symptoms (>1 week) warrant advanced imaging (AAN Practice Parameter 1997).
- ◆ MRI appears to be the diagnostic test of choice.



Lumbar Spine

- ◆ Acute Low Back Pain
- ◆ Chronic Low Back Pain



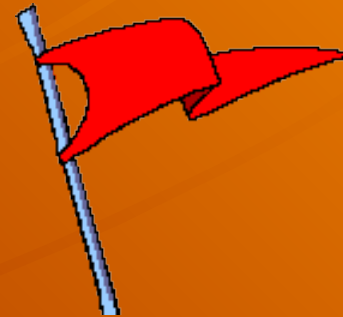
Acute Low Back Pain

◆ Indications for diagnostic imaging:

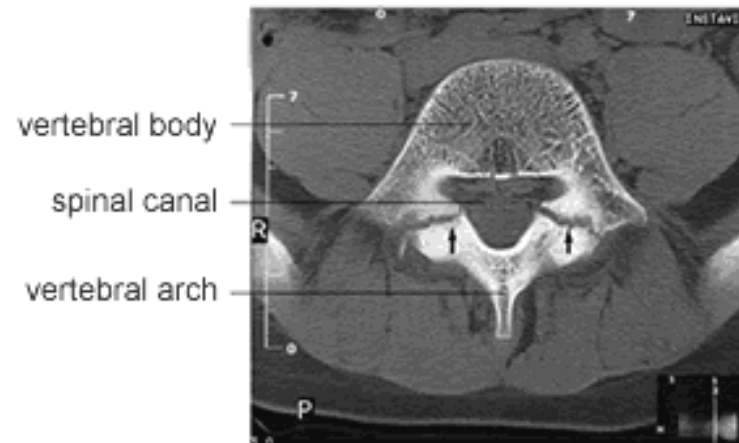
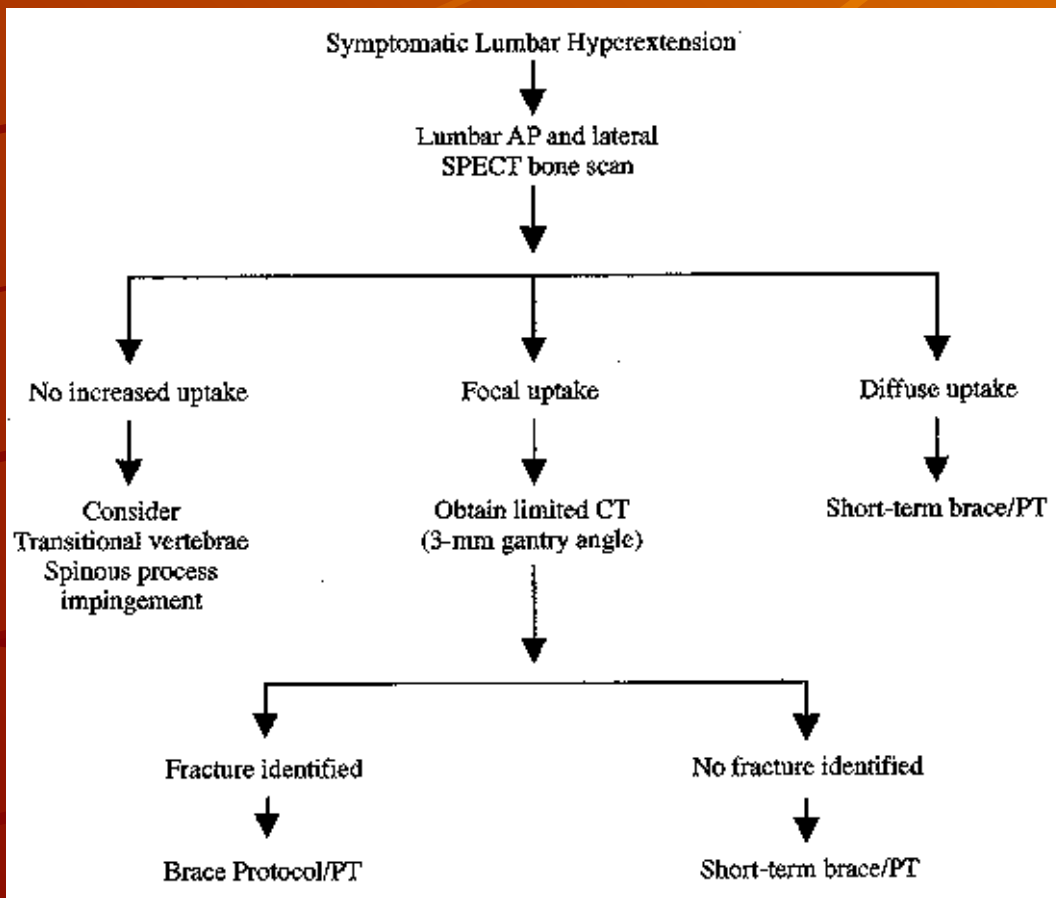
- Major trauma; age > 50; persistent fever; history of cancer; unremitting rest or night pain; major muscle weakness.

◆ AP, Lateral, LS spot view

◆ Advanced imaging as directed



Spondylolysis



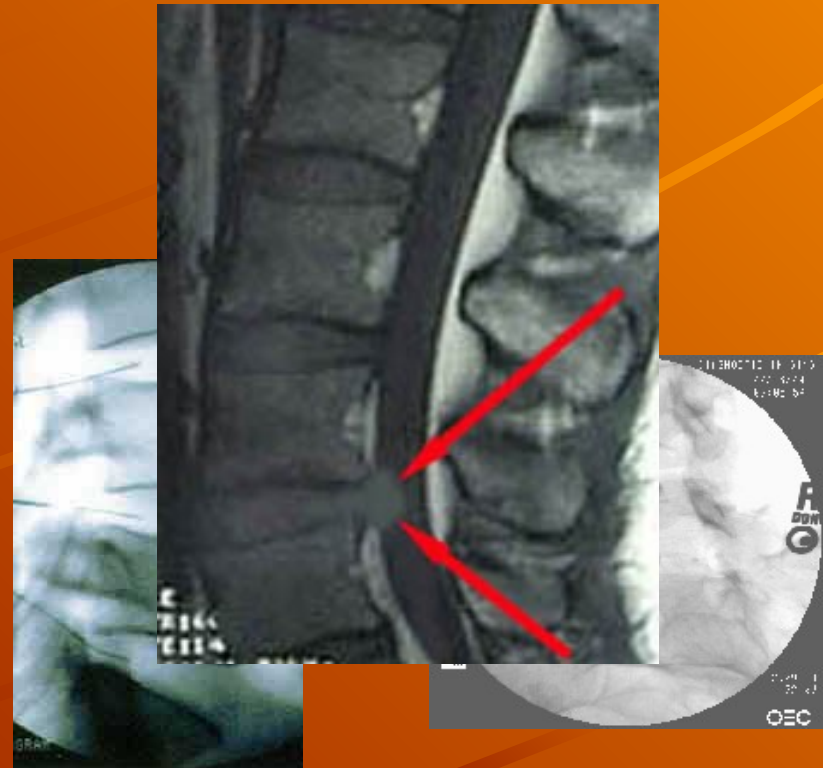
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d'Hemecourt P, Gerbino II PG, Micheli LJ: Back injuries in the young athlete.
Clin Sports Med 19:663-679, 2000

Chronic Low Back Pain

✦ Advanced imaging begins with a good history and physical examination:

- MRI
- CT myelogram
- Discogram
- Fluoroscopic SI and facet injections



Shoulder

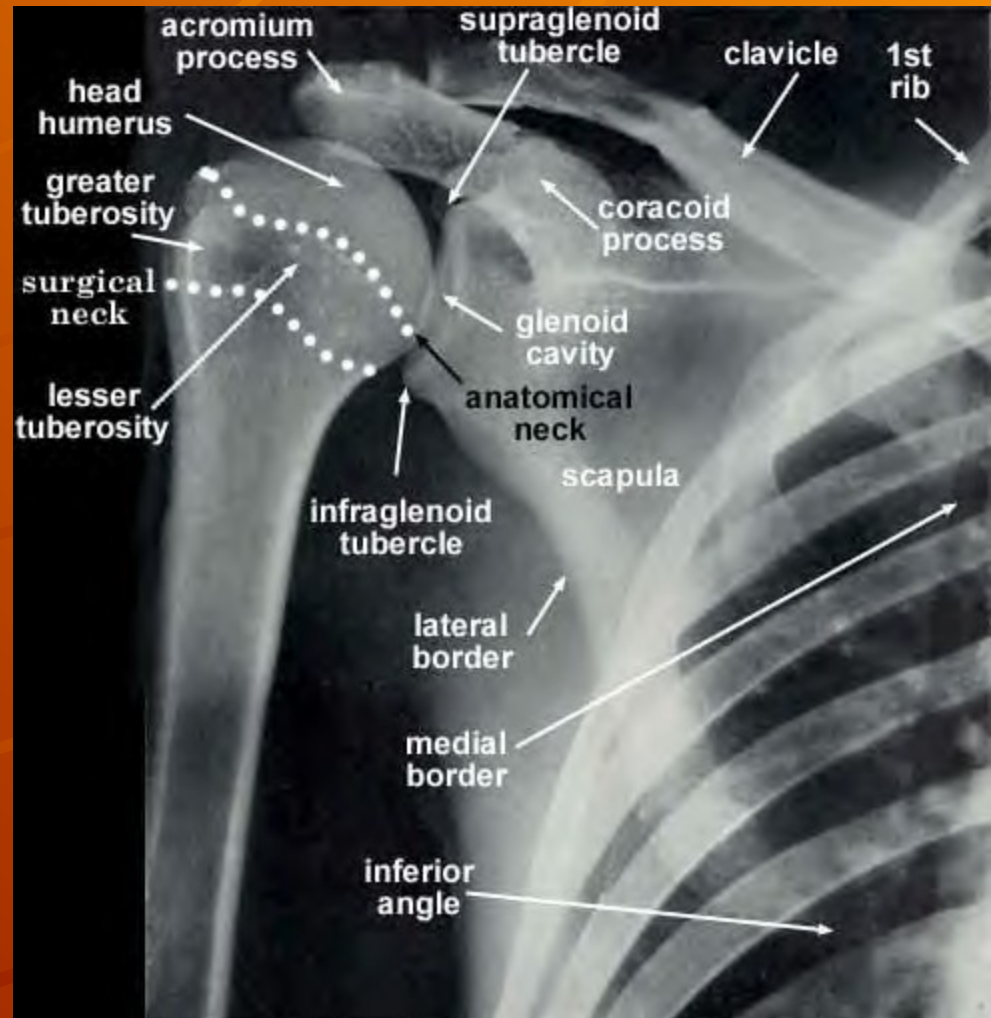
- ◆ Acute Shoulder Trauma
- ◆ Impingement
- ◆ Instability



Acute Shoulder Trauma

- ✦ Plain radiographs (5 views)
 - True AP, and AP in internal and external rotation
 - Transscapular and axillary views

- ✦ Complex fractures
 - CT



Impingement

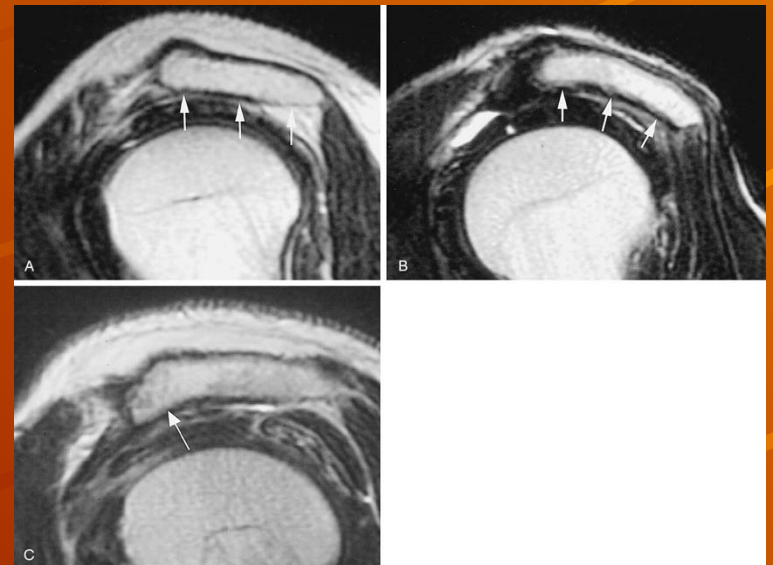
◆ Plain radiographs

- 30° caudal tilt view
- AC AP with Zanca
- 10° cephalad AP

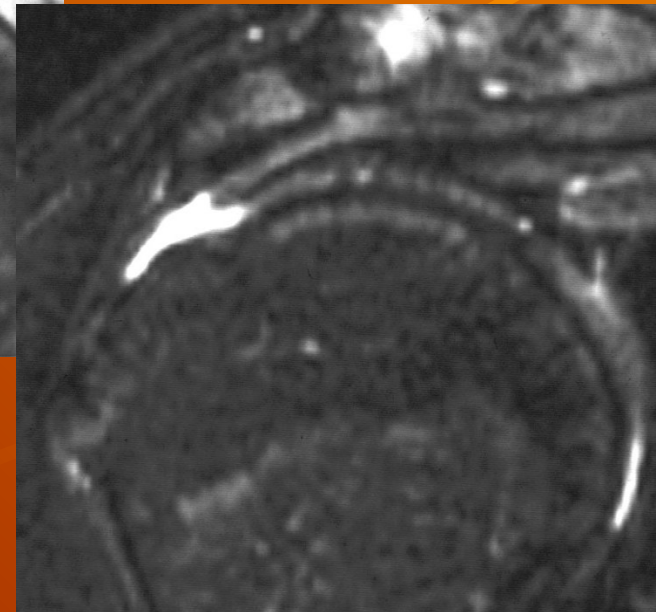
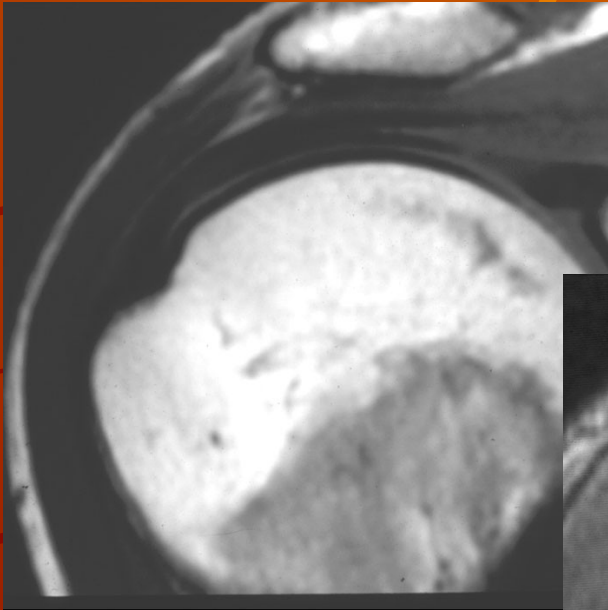


◆ MRI

- Tendinopathy
- AC arthropathy

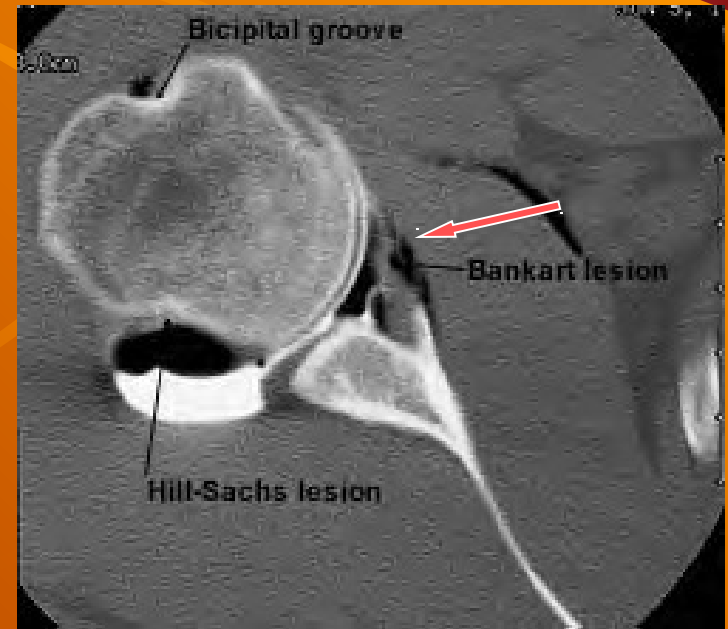


Imaging of Tendons: Shoulder



Instability

- Plain radiographs
 - ✦ West Point axillary view
 - ✦ Stryker notch view
- Labral Pathology
 - ✦ MRI with gadolinium
 - ✦ CT arthrography



Imaging of Ligaments: Shoulder



Humeral avulsion of the inferior glenohumeral ligament

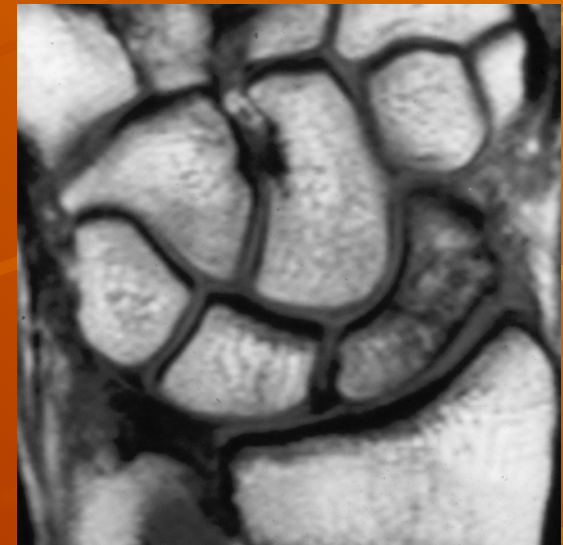
Wrist

- ◆ Acute Wrist Trauma
- ◆ Chronic Wrist Pain



Acute Wrist Trauma

- ✦ Standard views: PA and lateral
- ✦ Scaphoid fracture:
 - scaphoid view; if negative, immobilization for 2 to 3 weeks, followed by repeat films; if negative and symptomatic, limited MRI
- ✦ Hamate fracture:
 - carpal tunnel view; if negative CT scan



Wrist Instability

✦ PA and lateral radiographs

– PA view:

✦ constant 2 mm intercarpal joint space

✦ 3 arcs

– Lateral view:

✦ four Cs

✦ capitolunate angle 0-15 degrees

✦ scapholunate 30-60 degrees

– Stress views



Chronic Wrist Pain

- ◆ TFCC Injury
- ◆ Occult Ganglion
- ◆ Hamate Fracture
- ◆ Keinbock's Disease
- ◆ Complex Regional Pain Syndrome
- ◆ Carpal Instability
- ◆ Dorsal Impingement Lesions



Leg

Exertional Leg Pain

- Shin splints
- Stress fracture
- Exertional compartment syndrome
- Other

Evaluation:

- Plain radiographs
- AP, lateral
- Triple phase bone scan
- MRI
- MRA



Exertional Leg Pain

◆ Shin Splints

- clinical diagnosis
- plain films to r/o stress fracture

◆ Triple Phase Bone Scan

- Phase:

◆ Blood flow and Pool only;
classically no uptake on
delayed images.

- Appearance:

◆ linear not fusiform



Figure 4: Courtesy of Carlos E. Jimenez, MD

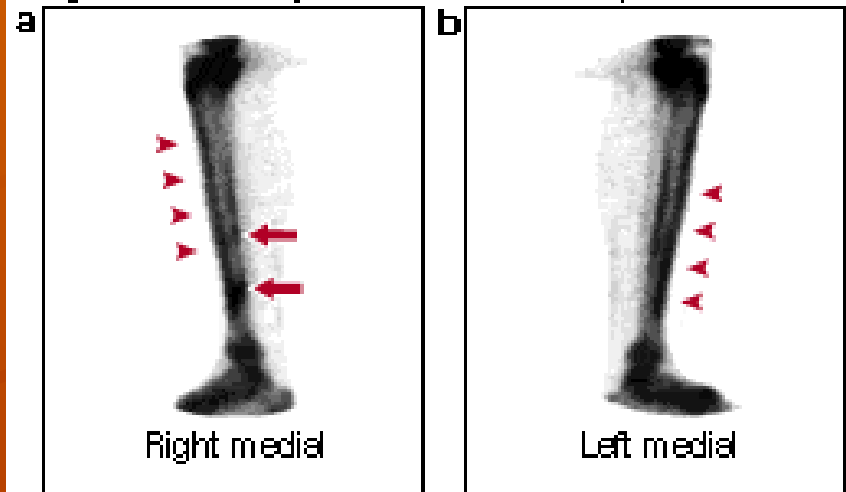
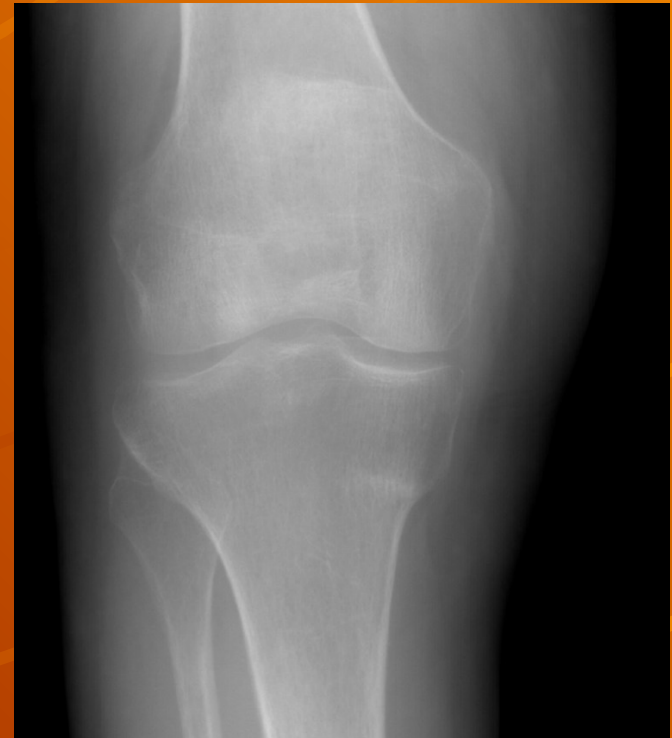


Figure 4. Medial views of a delayed bone scan show signs characteristic of stress fractures and periostitis in a 15-year-old female high school runner who presented with bilateral lower leg pain. Two fusiform areas of focal uptake in the right posterior tibial cortex (a, arrows) are consistent with stress fractures, and bilateral increased linear uptake along the anterior and posterior periosteum (a and b, arrowheads) are suggestive of periostitis in both legs. Periostitis is worse on the anterior surface.

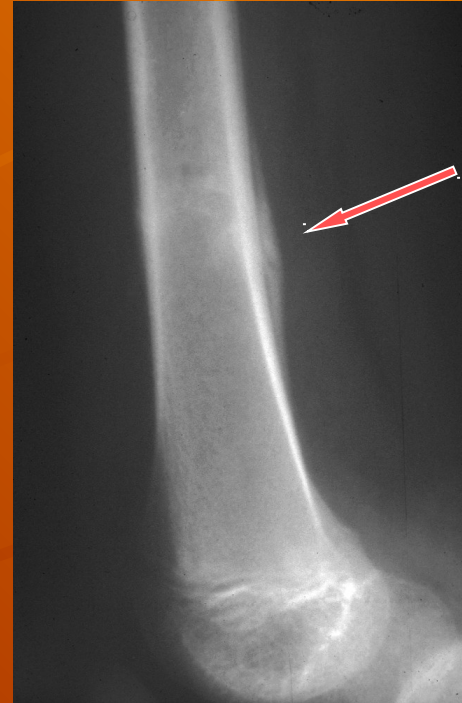
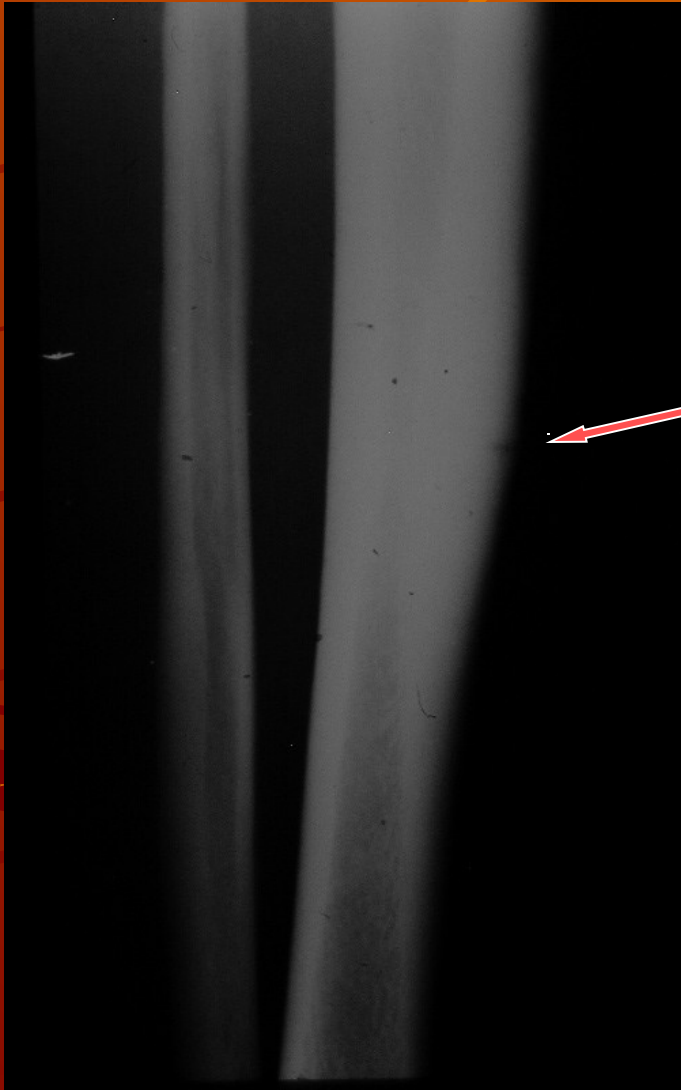
Stress (Overuse) Fractures

Initial radiograph normal in up to 70% of athletes at onset of pain



-Fluffy, ill-defined sclerotic line perpendicular to major trabecular lines

Stress (Overuse) Fractures



- Thin incomplete lucent line
- May proceed to completion
- Periosteal reaction

Imaging of Early Stress Fractures

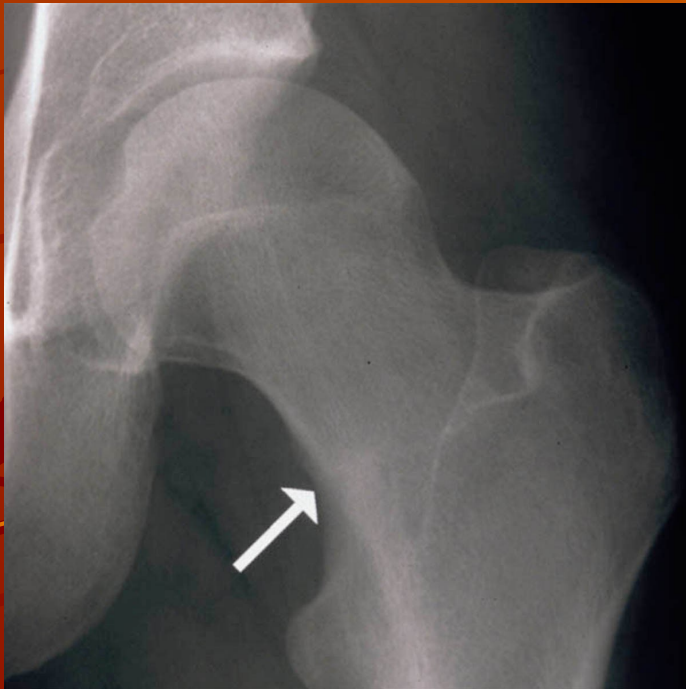
- MRI/ bone scan near 100% sensitivity
- MRI improved specificity



- Present on all three phases initially
- MRI improved specificity

Imaging of Early Stress Fractures

-Dark line on T1/T2 with edema



Chronic Exertional Compartment Syndrome

- ✦ Triple phase bone scan and MRI have not been shown to be reliable to date to replace clinical judgement with compartment pressure testing.
- ✦ Samuelson DR, Cram RL: The three-phase bone scan and exercise induced lower-leg pain: the tibial stress test. Clin Nucl Med 1996;21(2):89-93.



Popliteal Artery Entrapment Syndrome

- ✦ MRA with and without plantarflexion
- ✦ Angiography



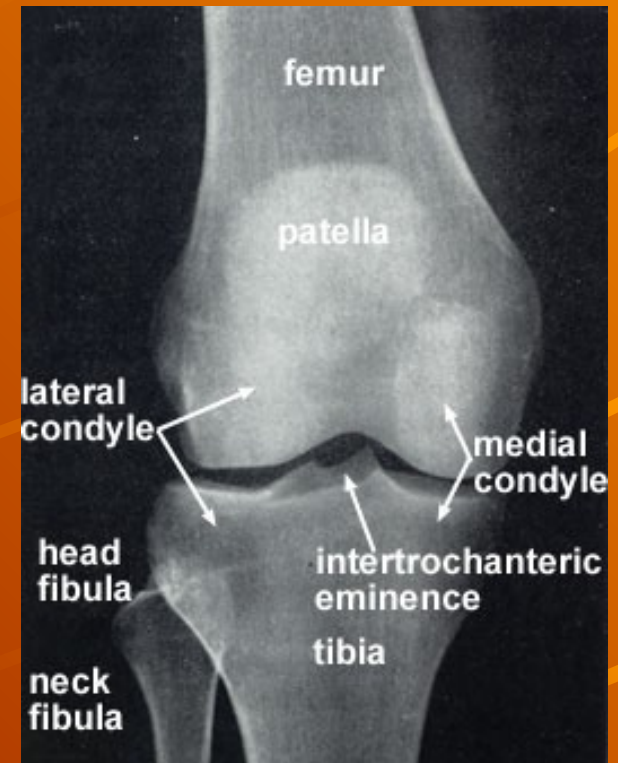
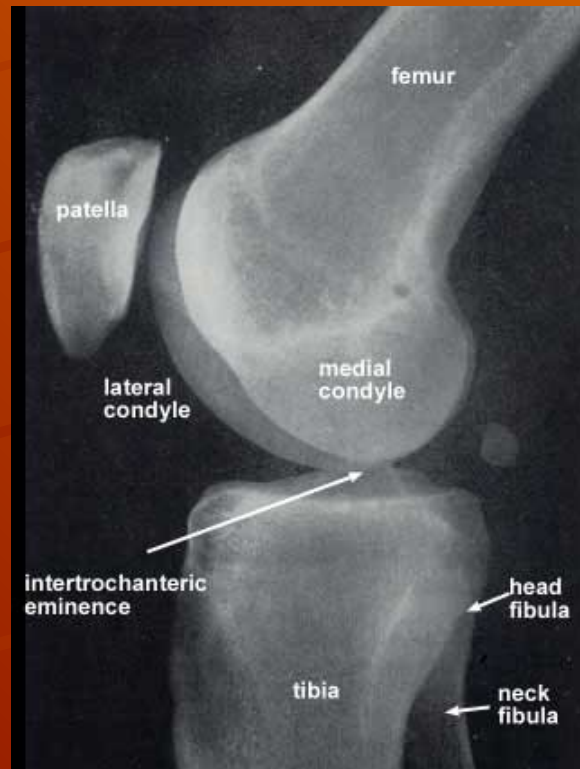
Knee

- ◆ Acute Knee Trauma
- ◆ Chronic Pain/Instability
- ◆ Patellofemoral Pain



Acute Knee Trauma

- ✦ AP, lateral 30° flexion
- ✦ CT scan for complex fractures
- ✦ MRI



Chronic Pain/Instability

✦ AP, 30° flexion lateral, 45° weight bearing flexion PA, weight bearing AP on long cassette

✦ MRI

- Meniscal injury
- Ligamentous insufficiency
- Osteochondral injury

Figure 2: Courtesy of Christopher D. Hamer, MD

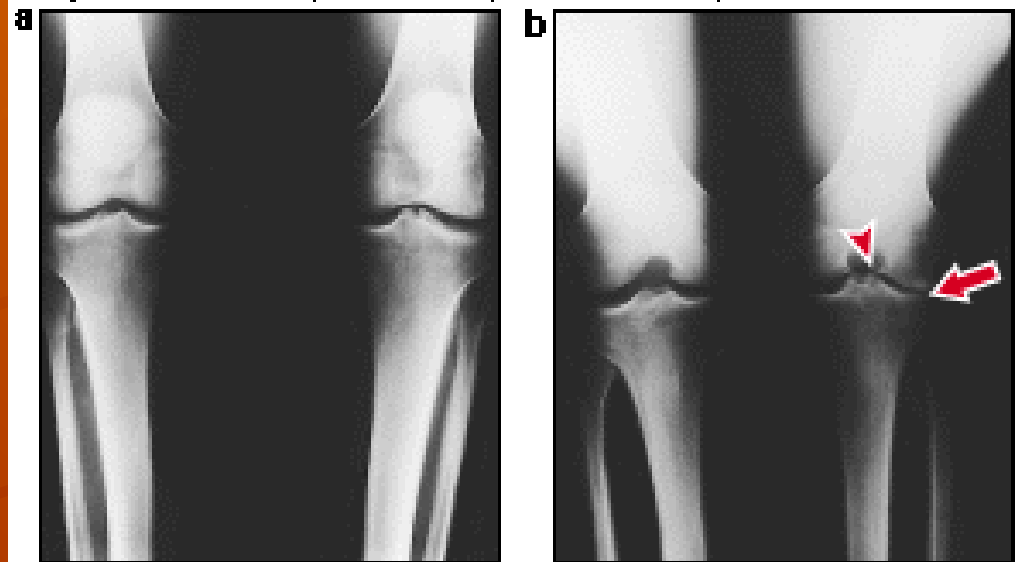
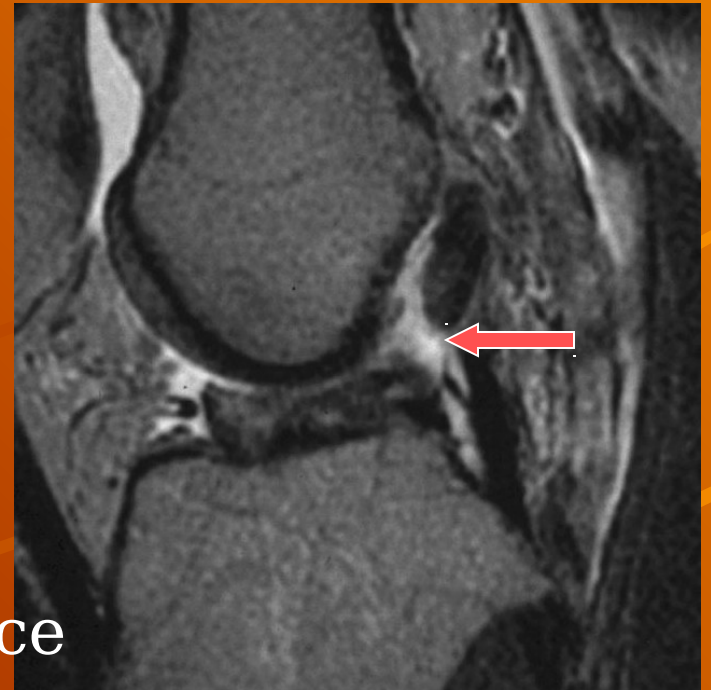


Figure 2. A weight-bearing anteroposterior (AP) radiograph (a) of a 35-year-old man with the knees in extension. The patient had two previous arthroscopic partial lateral meniscectomies and continuing lateral knee pain. Note the well-preserved joint spaces. A weight-bearing PA radiograph of the same patient with his knee in 45° flexion (b) shows decreased lateral joint space on the right (arrow), subchondral sclerosis, and osteophyte formation in the intercondylar notch (arrowhead). Given these findings, the patient has lateral compartment chondrosis, and an MRI scan is not indicated.

Imaging of Ligaments: Knee



- MRI imaging modality of choice
- T2 weighted images- pathology sequence

Imaging of Ligaments: Knee



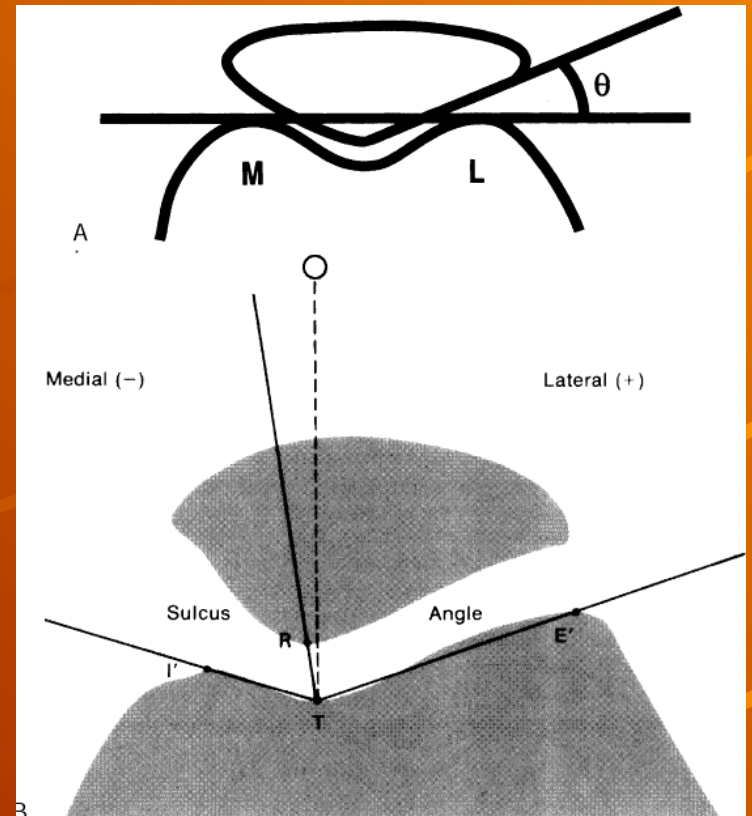
-Indirect signs of ligament disruption

Patellofemoral Pain

✦ AP, 30° flexion lateral, 45° weight bearing flexion PA, weight bearing AP on long cassette

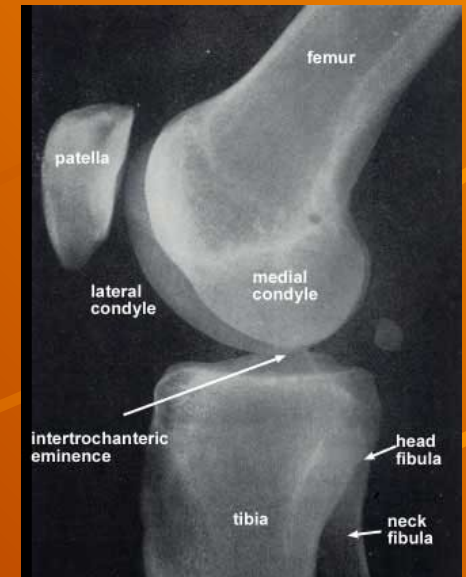
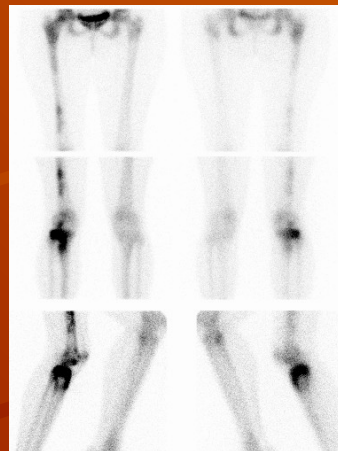
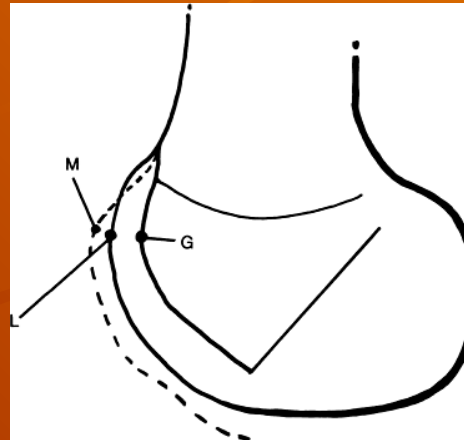
✦ Axial merchant view

- Lateral patellofemoral angle
 - ✦ angle should open laterally
- Congruence angle
 - ✦ > 16° abnormal

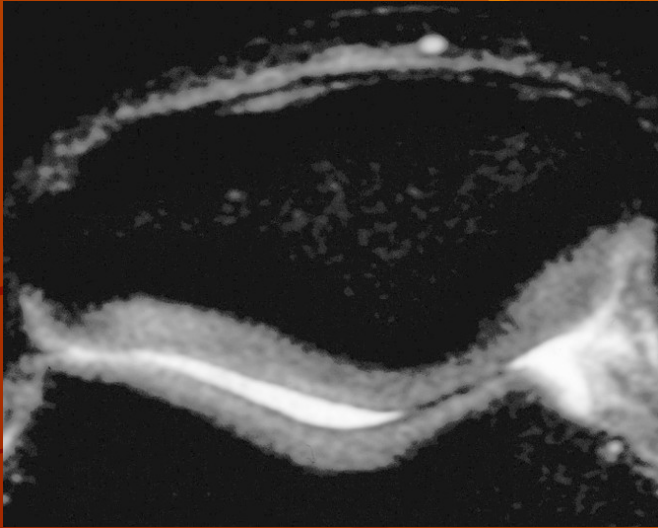


Patellofemoral Pain

- ◆ Trochlear depth: 1cm distal to central line origin should be greater than 5mm.
- ◆ Kinematic CT
- ◆ Progressive flexion views: 30, 45, 60 degrees
- ◆ Bone Scan



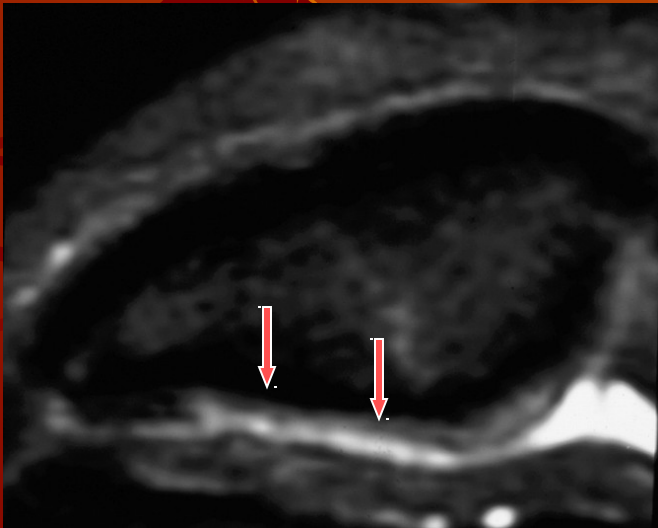
Imaging of Cartilage: Patella



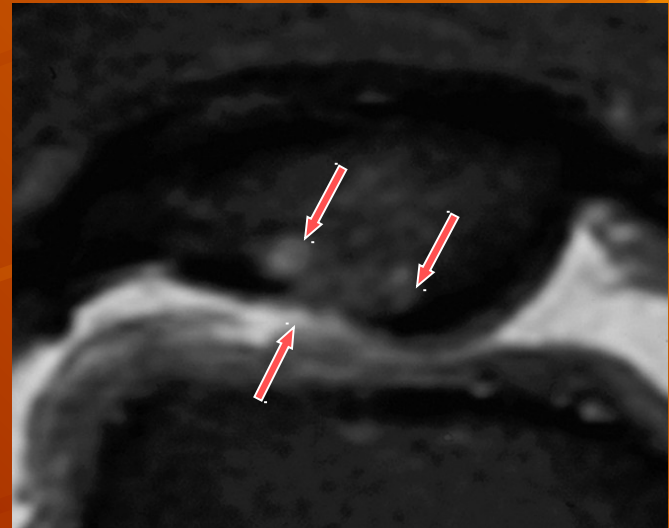
Normal patellar cartilage



Grade 1



Grade 2



Grade 4

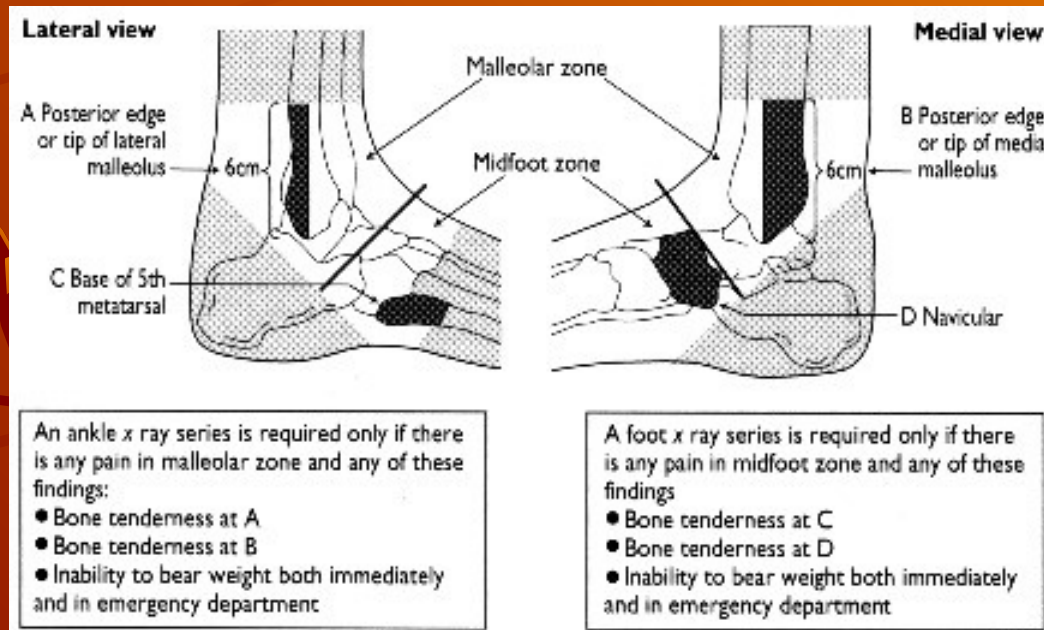
Ankle

- ◆ Acute Ankle Trauma
- ◆ Chronic Ankle Pain
- ◆ Chronic Ankle Instability



Acute Ankle Trauma

✦ Ottawa Ankle Rules:



Stiell IG, McKnight RD, Greenberg GH, McDowell I, Nair RC, Wells GA, et al. Implementation of the Ottawa ankle rules. *JAMA* 1994;271:827-32.

Acute Ankle Trauma

✦ AP, Lateral and mortise views



Don't forget the foot films!



Syndesmosis Imaging

◆ Tibiofibular overlap (1cm above the plafond):

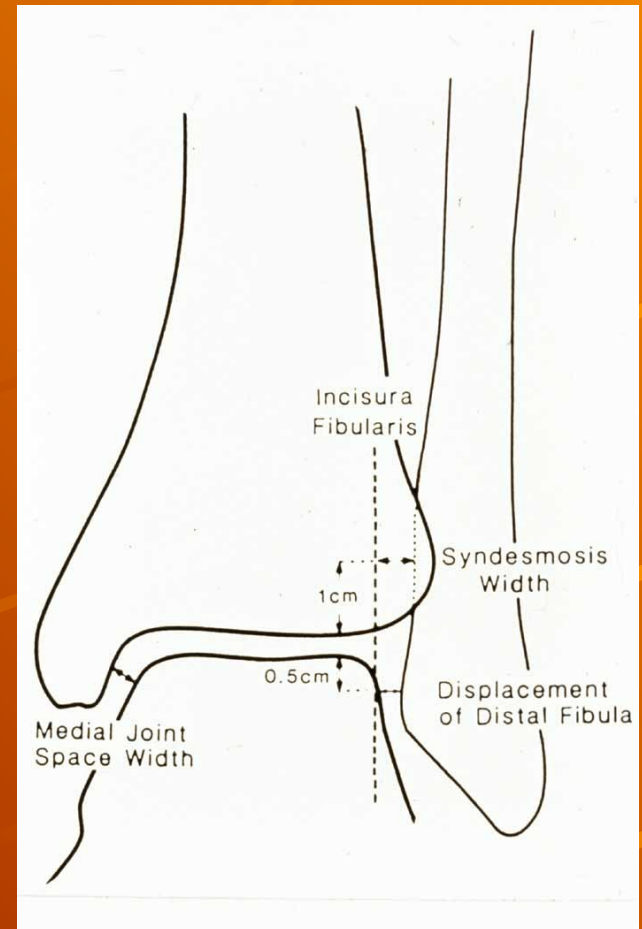
- AP: $> 6\text{mm}$
- Mortise: $> 1\text{mm}$

◆ Tibiofibular clear space:

- $< 6\text{mm}$ on AP or mortise

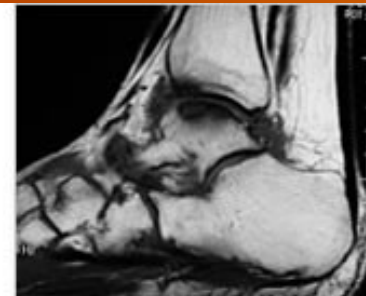
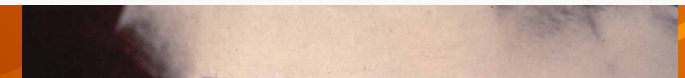
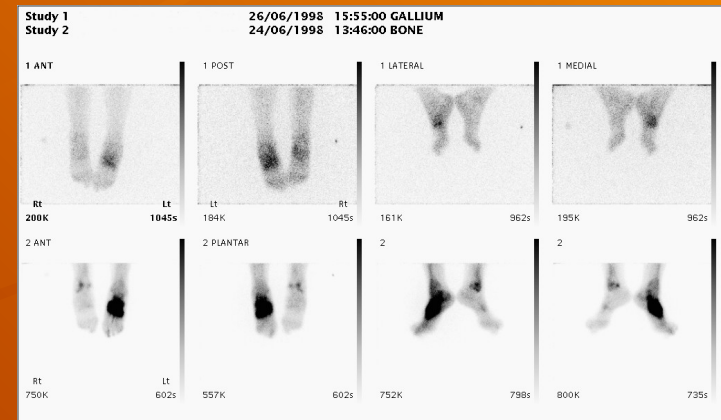
◆ Medial clear space (1cm below the tibial plafond):

- 2-4 mm normally



Chronic Ankle Pain

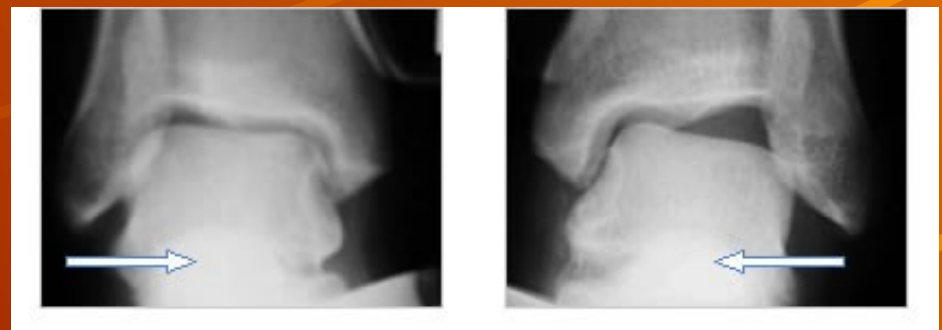
- ❖ Chronic ankle pain: osteochondral lesions, occult fractures, impingement lesions, tendon problems.
- ❖ MRI is thought to be the imaging modality of choice.
- ❖ Some authors recommend bone scan for diffuse nonspecific pain, with a f/u CT if needed as provides superior bone resolution.



Chronic Ankle Instability

✦ Ankle instability series:

- Anterior drawer: $> 5\text{mm}$ anterior translation compared with unaffected side.
- Talar tilt: >20 degrees or >10 degree variance from the contralateral side.



Conclusion

- ◆ Diagnostic imaging continues to readily evolve with improved technologies.
- ◆ The initial imaging tool of choice remains plain radiography.
- ◆ Advanced imaging is then based upon a carefully performed history and physical, and consultation with your regional radiologist.

